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Habitat factors influencing the brown rat *Rattus norvegicus* abundance on uninhabited island, South Korea

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Invasive rodents are significant issues for the conservation and management of habitats, particularly in island areas. Numerous studies have indicated that invasive rodents on islands directly or indirectly influence native plants and animals negatively. Consequently, many countries have made efforts to eradicate invasive rodents primarily using poison. However, these efforts have led to additional problems, such as the mortality of native animals due to intoxication. Understanding the habitat usage of species in local areas is essential for effective population management. So, we investigated the habitat usage of the invasive brown rat *Rattus norvegicus* on an uninhabited island. From October 2019 to November 2023, we surveyed field signs of brown rats on Yuksan Island, South Korea. To examine the interactions among habitat factors and brown rat abundance, we calculated 6 variables including the density of black-tailed gulls during the breeding season, normalized difference vegetation index (NDVI) for spring, summer, and fall, elevation, and slope. The results of the stepwise regression model revealed a strong correlation between the density of brown rat field signs and NDVI in summer. Additionally, elevation, slope, and NDVI in fall were correlated with brown rat abundance. The habitat factors related to brown rat abundance were associated with the availability of food resources and the quality of shelter, which is influenced by vegetation coverage, prevention of drowning, and species-specific behavior.

Keywords: habitat usage, invasive species, rodent, species-specific behavior, uninhabited island

Introduction

Generally, small rodents exhibit nocturnal activity and are closely associated with habitat structure, particularly ground and understory coverage (Bongiovanni et al. 2024; Imakando et al. 2023). Vegetation coverage on habitat were closely linked to the availability of food resources and shelter (Ganesh et al. 2024). Most of rodent were omnivorous and breed year-round, typically reproducing more than twice a year. Their short lifespan and the availability of food resources contribute to their high adaptability across various habitats (Harper et al. 2023; Samaniego et al. 2021). Furthermore, the genus *Rattus* has historically been closely associated with human activity. Palaeoecological, archaeological, and ecological studies suggest that the dispersal or introduced small rodents into new habitats can directly or indirectly impact native plants and animals (Drake and Hunt 2009; Michaux et al. 2007; Prebble and Wilmshurst

2009; van der Geer 2018).

The brown rat, or Norway rat *Rattus norvegicus* and the black rat *R. rattus* have been found in various habitats, ranging from urban areas to uninhabited islands (Feng and Himsworth 2014; Traweger et al. 2006). In some regions, these invasive rodents have caused significant issues, such as the spread of epidemic diseases and predation on local populations, particularly small-sized animals (Harper and Bunbury 2015; St Clair 2011). On Sasu Island, located in Jeju, South Korea, the brown rat *R. norvegicus* has been identified as a primary cause of hatching failures in the streaked shearwater *Calonectris leucomelas* (Nam et al. 2014). Consequently, many countries are making efforts to eradicate invasive rodents, especially on uninhabited islands. However, some efforts to remove the invasive rodents may inadvertently lead to additional problems, such as increased mortality among local wildlife due to intoxication (Taylor and Thomas 1989) and resistance from poi-



son (Brunton et al. 1993).

On the Korean Peninsula, there are 2,918 uninhabited islands (Ministry of Oceans and Fisheries 2020) and from 2005, 260 islands with highly valuable for their landscape or biodiversity have been designated specified islands and protected. To effectively manage these habitats and their populations, it is essential to understand the ecological interactions among habitats and the patterns of population. Therefore, we present the relationship between habitat characteristics and field signs of small rodent density, providing foundational information for managing the uninhabited islands of South Korea.

Materials and Methods

Study area

This study was conducted on Yuksan Island (35°19'14"N-35°19'26"N, 126°16'24"E-126°16'44"E) in the Chillsando Archipelago, Yeonggwang, South Korea, from October 2019 to November 2023 (Fig. 1). The island is protected by specified island and Natural monument. This is divided into two sides: the northeast and southwest. It covers an area of approximately 4.7 ha and has an altitude of 35 m above sea level. During the study period, the seasonal mean temperatures for spring, summer, and fall were 14.6°C, 24.8°C, and 15.9°C, while the recorded seasonal precipitation was 219.1 mm, 623.22 mm, and 308.76 mm, respectively. The vegetation on the island is predominantly composed of Indian goosegrass *Eleusine indica* and rapeseed *Brassica napus*, Oahu sedge *Carex wahuensis* var. *robusta* were located small patches. And during the breeding season for birds (May to July), over 25,000 individuals of black-

tailed gull *Larus crassirostris*, 400 individuals of black-faced spoonbill *Platalea minor*, and 200 individuals of Chinese egret *Egretta eulophotes* were observed using the island as a breeding site (National Institute of Ecology 2024).

Field survey and habitat factors

During the study periods, we surveyed the field signs of rodents, particularly focusing on tunnels, and recorded the spatial information of each tunnel using a GPS device (Garmin GPS 64s; Garmin, Lenexa, KS, USA). To minimize the impact on breeding birds, we conducted our surveys of rodent field signs exclusively in late fall (October to November). Additionally, we collected deceased rodents and utilized camera traps to gather information on the rodent composition in the study area. Throughout the study period, we collected 6 specimens and obtained 26,238 images from the camera traps over 3,588 hours (Fig. 2). Based on our morphological data, specimen analysis, and camera trap data, we identified only one species of rodent: the brown rat *R. norvegicus*. Consequently, we concluded that the field signs of rodents on Yuksan Island primarily represent those of the brown rat. We then calculated the density of rodent field signs (Fig. 3) within a 30 m × 30 m based on the home range of the brown rat (Hartley and Bishop 1979).

Moreover, we calculated the habitat characteristics of Yuksan Island, categorizing both biotic and abiotic factors. The biotic factors included the density of black-tailed gulls during the breeding season and the normalized difference vegetation index (NDVI). Although, we conducted a field survey of brown rat field signs only in the fall, rodents exhibiting burrowing behavioral characteristics had repaired tunnels (Vleck 1981; Witmer et al. 2012). Therefore, we uti-

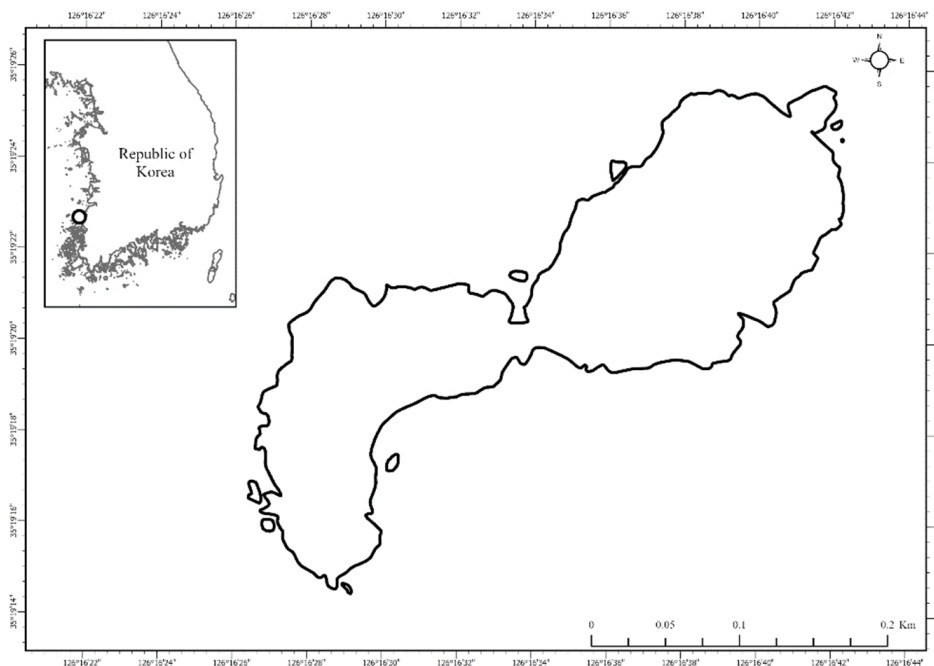


Fig. 1 Location of study area in Yuksan Island, South Korea.

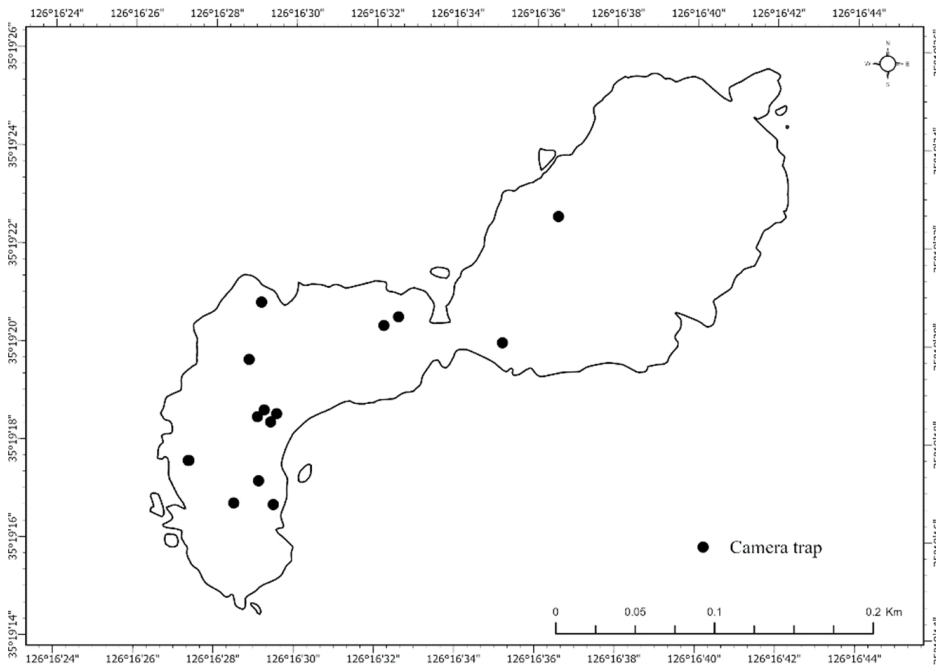


Fig. 2 Location of set up the camera traps in Yuksan Island, South Korea.

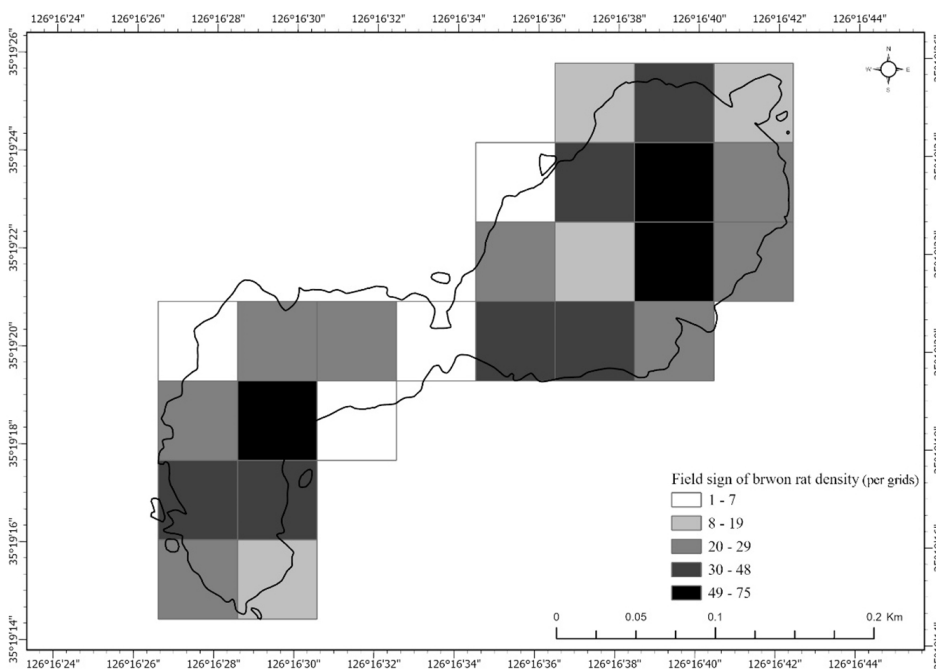


Fig. 3 Density of brown rat *Rattus norvegicus* within a 30 m × 30 m grids during the study periods.

lized the density of black-tailed gulls during the breeding season (spring and summer) and NDVI in spring, summer, and fall to access the biotic factors for affecting the density of brown rat. The abiotic factors encompassed the elevation using a digital elevation model (DEM) and slope (Table 1). First, we assessed the biotic factors in the study area. We filmed orthophoto in May of each year and then vectorized the spatial locations of black-tailed gulls for each year. The density of black-tailed gulls was calculated using a grid size of 1 m² to compare differences between the two sides of the study site (northeast and southwest). This was done in conjunction with grids of the same size used for assessing

rodent density, in relation to the abundance of brown rats. The NDVI was calculated based on Landsat 8 satellite imagery of seasons, as followed:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Second, the abiotic factors in the study area were assessed. DEM and slope were generated from digital topographic map. All habitat factors were analyzed using ArcGIS Pro (Esri, Redlands, CA, USA).

Statistical analysis

To assess the impact of habitat variables on the field sign density of brown rats, we conducted a statistical analysis using R (ver. 4.4.1). We conducted a Mann–Whitney U-test to assess the differences in habitat factors on each side of Yuksan Island. Additionally, we implemented a bidirectional stepwise regression model to evaluate the effects of 6 variables of habitat factors on the field sign density of brown rat (Table S1). To mitigate potential multicollinearity issues in the models, we calculated the variance inflation factors (VIF) for each influencing factor. The VIF for

each factor was less than 2, indicating no significant multicollinearity in the analysis.

Results

Using camera traps, the detectability of brown rats (*R. norvegicus*) in the study area increased in 2020. However, after 2021, the detectability of brown rats captured by camera traps decreased dramatically from 22.91% to 1.22% by 2023 (Table 2). The density of black-tailed gull, and NDVI during each season, spring, summer, and fall were not differed between two sides of study area (Table 3). However, elevation ($Z = -11.24, p < 0.01$) and slope ($Z = -8.86, p < 0.01$) were higher in northeast side than in southwest side significantly. The results of stepwise regression model indicated that NDVI on summer were correlated with density of brown rat stringently (Table 4). And elevation, slope, and NDVI on fall were correlated with density of brown rat. Other habitat factors, density of black-tailed gull and NDVI on spring did not relate with density of brown rat field sign.

Table 1 Characteristics of biotic and abiotic factors on study area

Categories	Factor	Source
Biotic	Density of black-tailed gull	Orthophoto
	NDVI_Spring	Landsat 8 satellite image, NASA
	NDVI_Summer	
Abiotic	NDVI_Fall	Digital topographic map
	Elevation	
	Slope	

NDVI: normalized difference vegetation index.

Table 2 Summary of the result on captured brown rat *Rattus norvegicus* by camera trap

Year	Initial date	End date	No. of total photograph	No. of brown rat photograph	Proportion of filmed brown rat (%)
2019	2019-10-10	2019-11-13	16,453	6,010	36.53
2020	2020-10-07	2020-11-12	2,421	1,401	57.87
2021	2021-06-01	2021-10-06	59,435	13,618	22.91
2022	2022-03-23	2022-11-09	83,085	3,280	3.95
2023	2023-03-10	2023-10-26	157,797	1,929	1.22

Table 3 Habitat factors of northeast (NE) and southwest (SW) sides in Yuksan Island, South Korea

Factor	NE		SW		Z	p
	Mean	S.E.	Mean	S.E.		
D.B.G. (no./m ²)	0.82	0.03	0.81	0.07	-0.12	0.90
NDVI_Spring	0.12	0.01	0.11	0.02	-0.43	0.67
NDVI_Summer	0.32	0.02	0.30	0.01	-0.56	0.57
NDVI_Fall	0.23	0.01	0.20	0.00	-1.77	0.08
Elevation (m)	18.71	0.00	10.26	0.00	-11.24	< 0.01
Slope (°)	25.56	0.03	18.47	0.03	-8.86	< 0.01

D.B.G.: density of black-tailed gull, NDVI: normalized difference vegetation index, S.E.: standard error.

Table 4 Results of stepwise regression model determine the effects of habitat valuables on field sign of brown rat *Rattus norvegicus* density in Yuksan Island, South Korea

Variables	Estimate	S.E.	t	Significance level	Partial r ²
Intercept	-0.917	0.530	-1.732	*	0.017
NDVI_Summer	6.420	1.867	3.495	***	0.860
Elevation	0.087	0.022	3.921	***	0.062
Slope	-0.038	0.016	-2.347	*	0.039
NDVI_Fall	-4.037	2.003	-2.015	*	0.020

NDVI: normalized difference vegetation index, S.E.: standard error. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Model $r^2 = 0.874, p < 0.001$.

Discussion

Brown rat in the Yuksan island, reported approximately 50–100 individuals (Cultural Heritage Administration 2004). Estimating population size using camera traps remains imprecise. However, the population of brown rats on Yuksan Island may be increasing, which also raises the probability of capturing them with camera traps. Our data indicate that the number of captured brown rats decreased after 2021. During our study period, we discovered rodenticide to a portion of the study area after October 2020. Consequently, we conclude that the brown rat population on Yuksan Island may be smaller than reported in the previous study conducted in 2004 and is declining annually.

Most studies examining small rodent populations have focused on vegetation coverage, particularly in the ground and understory (Lee et al. 2020). Generally, rodents are omnivorous and serve as a food resource for predators such as raptors and carnivores. Additionally, small-sized rodents feed on plant seeds and invertebrates found on the ground. Therefore, ground cover or understory vegetation provides both food resources and shelter for small rodents (Thompson and Gese 2013). NDVI represents the health and density of plant (Huang et al. 2021). Yuksan Island had a simple vegetation composition, predominantly covered by Indian goosegrass *E. indica* almost area after June. Higher NDVI values during the summer may indicate increased food resources and shelter for the brown rat population. Moreover, a previous study indicated that the brown rat in Yuksan island fed vegetable food resource especially seed and invertebrate (Kang et al. 2022). However, NDVI values during the spring did not relate brown rat abundance and NDVI values during the fall were negatively related to brown rat abundance. Yuksan Island serves as a breeding site for various birds such as, black-tailed gull *L. crassirostris*, black-faced spoonbill *P. minor*, Chinese egret *E. eulophotes*, Chinese crested tern *Thalasseus bernsteini*. During the breeding season, from April to July, over 25,000 black-tailed gulls inhabit Yuksan Island. This high density of nesting birds results in significant excretion of acidic droppings, which may negatively impact plant growth due to increased soil acidity and compaction (Kolb et al. 2015; Korobushkin and Saifutdinov 2019). Consequently, the NDVI during spring is notably low and may not correlate with brown rat abundance. Furthermore, the NDVI in the fall shows a negative correlation with brown rat abundance, possibly due to the observational challenges presented by denser vegetation. Such vegetation can obscure the detection of field signs of brown rats, particularly their tunnels. Therefore, our results indicate that NDVI, which reflects vegetation coverage, is closely related to brown rat abundance, aligning with findings from other studies.

On the island, low elevation levels are associated with increased mortality due to drowning (Carpenter et al. 2022;

Husson et al. 2019). Higher elevations provide some stability against drowning, but they are still affected by strong winds. Rising above the sea levels have led to increased wind speeds on the island and in mountainous habitats (Solano et al. 2021). Strong winds also contribute to the mortality of brown rats (Gao and Li 2016). Small rodents on Korea peninsula, weighted from 3 and 500 grams, cannot withstand strong winds. Consequently, they prefer habitats rich in rocks, ground vegetation, woody plants, and hydrophytes (Villarreal et al. 2022). So, density of these plants serves as a windbreak, providing food resources and shelter. However, in our study area, Yuksan Island, the elevation is very low, with a maximum height of 35 meters. The ground coverage and breeding density of black-tailed gulls at our study site were similar on both the northeast and southwest sides, despite differences in elevation. Therefore, in our study, atmospheric factors, including wind speed, were consistent locally. As a result, we concluded that the abundance of brown rats in this study was related to their avoidance behavior to prevent drowning.

Similar to elevational levels, slope also influences the habitat utilization of rodent populations (Shuai et al. 2017). Our results indicate that an increasing slope gradient and soil erosion are negatively correlated with the abundance of brown rats. As the slope increases, the probability of falling and the energy required for climbing also rise (Birney-Jeffery and Higham 2014; Nations et al. 2019). Furthermore, slope affects the quantity of food resources and the quality of shelter, which are contingent upon the amount of vegetation and the extent of soil erosion (Lee et al. 2022). An increasing slope gradient can directly lead to soil erosion due to gravitational forces, resulting in decreased plant germination because of the loss of essential nutrients and water for seeds. This situation further exacerbates soil erosion by diminishing the soil's capacity to retain moisture, as the roots of plants become compromised (Reubens et al. 2007; Vannoppen et al. 2017). Moreover, the general distribution of rodents in mountainous habitats on the Korean Peninsula, Korean red-backed vole *Craxomys regulus*, Korean field mouse *Apodemus peninsulae*, and the striped field mouse *Apodemus agrarius*, all of which exhibit limited digging abilities. In contrast, the brown rat *R. norvegicus* demonstrates a high capacity for digging (Jo et al. 2018). Species-specific behaviors also interact with habitat usage, which are critical factors influencing habitat preference at the species level (Leclerc et al. 2016; Piper 2011). The brown rat, with its superior digging ability, tends to avoid steep slopes and areas prone to soil erosion to maintain tunnel stability. Rodent tunnels serve various purposes, such as storing food resources, breeding young, sleeping, and providing safe passage to other areas (Horner et al. 2016). Although we could not establish a direct relationship between soil erosion and the abundance of brown rat field signs, the interaction between slope, which affects

soil erosion, and brown rat abundance may indicate the impact of soil erosion on the population of brown rats.

Our results indicated that the interaction between habitat factors and brown rat abundance on uninhabited islands is significant. The habitat usage of brown rats was correlated with both biotic and abiotic factors, which may relate to their stability in terms of survival, feeding, and avoiding drowning. However, we did not observe population dynamics or seasonal habitat usage of brown rats in the study area due to limitations in accessing the island and the presence of breeding birds, particularly endangered species such as the black-faced spoonbill, Chinese egret, and Chinese crested tern. In the future, studies on seasonal habitat usage and population dynamics should be conducted to gain a clearer understanding of the habitat preferences of rodents on uninhabited islands. Additionally, information regarding the interactions among vegetation, rodents, and topological factors, such as soil texture and soil erosion, could elucidate the impact of species-specific behavior on habitat preference.

Supplementary Information

Supplementary information accompanies this paper at <https://doi.org/10.5141/jee.25.032>.

Table S1. Models based on the correlated AIC developed to explain the relative abundance index of brown rat (*Rattus norvegicus*) in each habitat variables ranked by the AIC value resulted by the stepwise regression model.

Abbreviations

NDVI: Normalized difference vegetation index

DEM: Digital elevation model

VIF: Variance inflation factors

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Not applicable.

Authors' contributions

Hyun-Gi Cha conceived the ideas, conducted the field survey, and wrote the original paper. Hyejin Kim performed the data analysis and contributed to writing the original paper. Hyun-Su Hwang conceived the ideas, conducted the field survey, analyzed the data, wrote the original paper, and reviewed and edited the final edition. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed in current study are available

from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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